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CALCULATION OF BLOWOUT GUN NOZZLE TEMPERATURES

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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Small laboratory devices such as the 37mm blowout gun at the BRL have a long history in unraveling the factors influencing gun barrel wear. Such devices are particularly useful when testing scarce and expensive experimental propellants. An unresolved question is whether relative propellant erosivity measured in such laboratory devices correlates with large-caliber gun wear.

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20. ABSTRACT (Contd)

To try to answer the question, Nordheim's scheme for computing heat transfer in guns and erosion vents was used to calculate bore surface temperatures in a 17.3 mm diameter nozzle for a series of five propellants for which the wear had already been measured. Empirical expressions for estimating wear in guns suggested the wear should increase exponentially with peak bore surface temperature if the nozzles mimicked wear in guns. A linear-least squares of natural log of wear vs. peak temperature showed the wear in nozzles could be fit to such an expression, specifically $\ell n\ \omega = -9.7 + 0.0094\ T$, where T is the peak surface temperature in Kelvin and wear is expressed as μ/shot.

To test how well the dependence of wear on bore surface temperature compares to large caliber guns, bore surface temperatures computed by Calspan from heat input measurements in the 155m M185 cannon were plotted against wear. The slope was 0.0076 K^{-1} suggesting the blowout gun wear may exaggerate relative wear expected in a large-caliber gun by ten percent.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

Small laboratory devices such as vented chambers or blowout guns have a long history in understanding gun barrel wear.[1] Compared with large-caliber gun tests, such devices need less propellant, need less room for safe firing, and have inserts which can be removed for post-firing analysis. An unanswered question is how to relate wear in the devices with wear in large-caliber guns. A recent JANNAF workshop concluded that laboratory devices cannot evaluate wear-reducing additives,[2] and that test devices in three laboratories have given contradictory results with the same propellants.[3,4]

This report attempts to relate erosivity from propellants in the BRL 37mm blowout gun to wear expected in large caliber guns. Empirical formulas[5,6] presume the wear is exponentially proportional to the maximum bore surface temperature. Bore surface temperatures in the empiracal models are estimated with interior ballistic parameters such as charge weight, flame temperature, gun diameter, and peak pressure.[7,8]

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[1] *"Hypervelocity Guns and the Control of Gun Erosion," Summary Technical Report of Division 1, NDRC, Volume 1, Washington, DC 1946.*

[2] *J.A. Lannon and J.R. Ward, "Workshop Report on Wear-Reducing Additives and Their Performance in Guns,"Proceedings of the 17th JANNAF Combustion Meeting, CPIA Publication 329, November 1980.*

[3] *A.J. Bracuti, L. Bottei, J.A. Lannon, and L.H. Caveny, "Evaluation of Propellant Erosivity with Vented Chamber Apparatus," 1980 JANNAF Propulsion Meeting, CPIA Publication, 315, March 1980.*

[4] *J.R. Ward, R.W. Geene, A. Niiler, A. Rye, and B.B. Grollman, "Blowout Gun Erosivity Experiments with Double-Base, Triple-Base, and Nitramine Propellants, 1980 JANNAF Combustion Meeting CPIA Publication, 315, March 1980.*

[5] *J.M. Frankle and L.R. Kruse, "A Method for Estimating the Service Life of a Gun or Howitzer," BRL Memorandum Report No. 1852, June 1967.* (AD #818348)

[6] *C.S. Smith and J.S. O'Brasky, "A Procedure for Gun Barrel Life Estimation," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, ADPA, Dover, NJ, March 1977.*

[7] *J. Corner, Theory of the Interior Ballistics of Guns, John Wiley & Sons, Inc., NY, 1950.*

[8] *L.W. Nordheim, H. Soodak, and G. Nordheim, "Thermal Effects of Propellant Gases in Erosion Vents and Guns," NDRC Armor and Ordnance Report No. A-262, March 1944.*

This report uses Nordheim's scheme to compute the peak surface temperatures during wear tests of five propellants.[9] If the relative wear of the propellants in the blowout gun is the same as in large guns, then a plot of natural logarithm of wear vs peak temperature should be linear, with the slope identical to that in guns. Wear tests in Reference 9 incorporated Niiler's radioactive technique[10] to correlate mass loss and diameter change.

II. INPUT PARAMETERS AND COMPUTER CODES

Three computer codes were used to perform the calculations discussed in the report. The first program, IB 3/70, computes interior ballistics data for guns. The second program, NOZZLE, computes interior ballistic data for a blowout gun with an erosion nozzle. The third program, NEWNSN, computes heat transfer using files of IB 3/70 and NOZZLE. Listings for each program are contained in the Appendix.

The assumed heat input, as described fully in Reference 8, was taken to be

$$Q = \tfrac{1}{2}\lambda C_p \rho U \Delta T \quad , \tag{1}$$

where q = heat flux, $J/m^2 \cdot s$,

λ = friction factor,

C_p = specific heat, $J/kg \cdot K$,

ρ = propellant gas density, kg/m^3,

U = gas velocity, m/s, and

ΔT = temperature difference between propellant gas and wall, K.

Following Nordheim's method, a friction factor of 1/253 was used for the 17.3 mm diameter nozzle.

Computations were done for the five propellants evaluated in Reference 9. The compositions are listed in Tables 1 and 2.

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[9] *R.W. Geene, J.R. Ward, T.L. Brosseau, A. Niiler, R. Birkmire, J.J. Rocchio, "Erosivity of a Nitramine Propellant," BRL Technical Report No. 02094, August 1978.* (AD #A060590)

[10] *S.E. Caldwell and A. Niiler, "The Measurement of Wear from Steel Using the Radioactive ^{56}Co," BRL Report No. 1923, September 1976.* (AD #A030262)

TABLE 1. COMPOSITIONS AND GRAIN DIMENSIONS OF M30 AND HFP PROPELLANTS

	M30 PPL-A-6372	HFP PPL-A-6380
Nitrocellulose (12.6%N)	28.0%	29.3%
Nitroglycerin	22.5	22.7
Nitroguanidine	47.7	5.0
RDX		36.5
Dioctylphthalate		5.0
Ethyl Centralite	1.5	1.5
Cryolite	0.3	
Total Volatiles (Residual)	0.2	0.3
Grain Length, mm	7.78	10.58
Grain Diameter, mm	1.59	2.37
Grain Perf. Diameter, mm	0.46	0.77
Grain Web, mm	0.56	0.80
Grain Geometry	SP	SP

TABLE 2. COMPOSITIONS AND GRAIN DIMENSIONS OF M5, M8, AND M1 PROPELLANTS

	M5	M8	M1
Nitrocellulose (13.25%N)	81.95%	52.15%	85.00%
Nitroglycerin	15.00	43.00	
Ethyl Centralite	0.60	0.60	
Barium Nitrate	1.40		
Potassium Nitrate	0.75	1.25	
Diethylphtalate		3.00	
Dinitrotoluene			10.00
Dibutylphthalate			5.00
Diphenylamine, Added			1.00
Ethyl Alcohol, Residual	2.30	0.40	0.75
Water, Residual	0.70		0.50
Graphite	0.30		
Grain Length, mm	10.58	25.4	8.26
Grain Diameter, mm	3.92	12.7	3.68
Grain Perf. Diameter, mm	0.41		0.37
Grain Web, mm	0.69	0.56	0.64
Grain Geometry	7 Perf	Strip	7 Perf

Propellant parameters required for the computations are listed in Table 3.

The term, B/W, is used to relate burning rate, r, with chamber pressure, P, and propellant web, W, by

$$r = (P + 44.8)\left(\frac{B}{W}\right) \cdot W \quad . \tag{2}$$

Propellant webs are listed in Tables 1 and 2.

For the blowout gun, chamber volume and nozzle area were 315 cm^3 and 2.36 cm^2, respectively.

III. RESULTS AND DISCUSSION

The experimental results from Reference 9 are listed in Table 4.

Table 5 gives calculated time to maximum pressure, peak nozzle surface temperature, heat input, and time from nozzle rupture to peak nozzle surface temperature.

A linear least squares fit tested the exponential dependence of wear with peak surface temperature.

$$\ell n\ (w) = a + bT \quad , \tag{3}$$

where w = wear, μ/shot,

T = peak bore surface temperature, K, and

a,b = constants.

The best fit values of a and b were -9.7 ± 2 and 0.0094 ± 0.002, respectively, with error representing one standard deviation. Table 6 compares experimental wear and wear computed with Eq. (3). Eq. (3) clearly underestimates wear for M1 with a peak temperature of 773 K. Frankle-Kruse also noted their expression was invalid below 900 K; Smith-O'Brasky report a similar threshold of 750 K.

A check on how wear varies with peak bore surface temperatures in guns can be made with bore surface temperature computations by Vassallo and coworkers at Calspan Corporation[11] in the M185 cannon. The Calspan workers compute peak bore surface temperatures from measured total heat input.[12] Recent work in a shock-tube gun with different metals showed temperature calculations starting with measured total heat input could

TABLE 3. PROPELLANT PARAMETERS*

Propellant	B/W, 1/MPa-s, x 10^5	Specific Heat J/gK	Impetus, J/g	Flame Temp, K	Ratio of Specific Heat	Co-Volume cm^3/g
M1	4.8	1.83	1,092	2,417	1.26	1.11
M5	7.0	1.77	1,270	3,245	1.23	1.00
M8	8.2	1.74	1,367	3,695	1.22	0.97
M30	6.2	1.86	1,303	3,040	1.24	1.06
HFP	4.8	1.84	1,412	3,255	1.24	1.07

All propellants assumed to have a density of 1.6 g/cm.

TABLE 4. EXPERIMENTAL DATA FROM BLOWOUT GUN EXPERIMENTS

Propellant	Charge,g	Peak Chamber Pressure,MPa	Time From Ignition to Rupture, ms	Flow Duration,ms	Mass Loss* mg/shot	No. of Shots
M1	70	193	7.5	4.5	1.5 ± 0.6	12
M1	86	283	7.0	6.5	0.8 ± 1.0	3
M5	60	193	6.3	4.5	5.0 ± 1.7	12
M5	77	283	5.0	6.4	25.9 ± 0.9	2
M5	100	413	3.6	7.7	116.4	1
M8	58	193	4.5	4.5	17.7 ± 4.2	12
M8	69	283	2.5	6.5	60.8 ±12	3
M8	100	413	2.0	7.4	306.5	1
M30	58	193	6.2	4.5	2.9 ± 0.9	12
M30	75	283	4.2	6.5	3.5 ± 1.3	3
M30	100	413	3.5	7.5	23.8	1
HFP	54	193	8.3	4.4	3.1 ± 1.0	12
HFP	70	283	5.8	6.3	7.1 ± 0.2	3
HFP	90	413	5.0	7.0	42.9	1

* *Sample mean and sample standard deviation.*

TABLE 5. COMPUTED HEAT TRANSFER RESULTS

Propellant	Charge, g	Cal'd Time From Ignition to Pmax, ms	Peak Temp, K	Cal'd Time From Pmax to Peak Temp, ms	Heat Input, J/mm^2	Nozzle Wear, μ/Shot
M1	70	8.2	773	1.0	0.464	0.2
M1	86	7.4	875	0.8	.519	0.1
M5	60	5.9	982	1.0	.623	0.8
M5	77	5.2	1155	0.8	.732	4.1
M5	100	4.4	1250	0.7	.854	18.5
M8	54	4.1	1107	0.8	.657	2.8
M8	69	3.7	1210	0.7	.787	9.6
M8	100	2.7	1407	0.6	1.000	48.6
M30	58	5.1	966	0.9	0.569	0.5
M30	75	4.6	1130	0.6	.657	0.6
M30	100	3.6	1228	0.5	.778	3.8
HFP	54	6.6	968	1.2	.573	0.5
HFP	70	5.9	1150	0.7	.669	1.1
HFP	90	4.9	1235	0.5	.782	6.8

TABLE 6. COMPARISON BETWEEN EXPERIMENTAL WEAR AND WEAR COMPUTED WITH EQUATION (3)

Propellant	Peak Temp., K	Wear exp't, μ/Shot	Wear Cal'd, μ/Shot
M1	773	0.2	0.0005
M1	875	0.1	0.2
M30	966	0.5	0.5
M30	1,130	0.6	2.5
M30	1,228	3.8	6.2
HFP	968	0.5	0.5
HFP	1,150	1.1	3.0
HFP	1,235	6.8	6.6
M5	982	0.8	0.6
M5	1,155	4.1	3.1
M5	1,250	18.5	8.3
M8	1,107	2.8	2.0
M8	1,210	9.6	5.0
M8	1,407	48.6	32.1

predict correctly whether the melting point of the metal was exceeded. Starting conditions in the shock-tube gun were varied to produce temperature bracketing the metals' melting temperatures.[13]

Table 7 shows bore surface temperatures computed for three 155mm propelling charges which have no wear-reducing additive. Wear data is available for the M119 and the XM201E2 charges.[14,15] Wear sensor data in the M185 cannon showed the XM208 minus its additive was five times as erosive as the XM201E2. Wear of the XM208 was presumed to be five times greater than the measured wear of the XM201E2 charge. A least-squares fit of the three points in Table 8 to Eq. (3) produced values of a and b of -7.4 and $0.0076K^{-1}$, respectively.

TABLE 7. BORE SURFACE TEMPERATURES AND WEAR FOR 155mm CHARGES WITHOUT ADDITIVE

Charge	Peak Temp, K	Wear, μ/shot	Ref.
M119	961	0.9	15
XM201E2	1,100	2.6	16
XM208 (no additive)	1,306	12.5	12

Figure 1 plots wear vs peak bore temperature for the nozzle and the 155mm gun. Figure 1 suggests relative wear among propellants will be overestimated compared with wear in guns by ten percent. Nonetheless, the agreement seems close enough to suggest relative propellant erosivity can be inferred in nozzles.

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[11] *F.A. Vassallo, "An Evaluation of Heat Transfer and Erosion in the 155 mm M185 Cannon," Calspan Technical Report No. VL-5337-D-1, July 1976.*

[12] *F.A. Vassallo, "Mathematical Models and Computer Routines Used in Evaluation of Caseless Ammunition Heat Transfer," Calspan Technical Report No. GM-2948-2-1, June 1971.*

[13] *F.A. Vassallo and W.R. Brown, "Shock Tube Gun Melting Erosion Study," BRL Contractor Report No. 406, August 1979.* (AD #A076219)

[14] *J.J. Reed and J.P. Cherry, "Service Tests of 155mm Howitzer, Self-Propelled Equipped with XM185 Tube," Field Artillery Board Report. Ft. Sill, OK, January 1970.*

[15] *J.A. Demaree, "155mm M185 Tube Wear Tests of Charge, Propelling XM201," Interim Report, JPG-76-601, June 1976.*

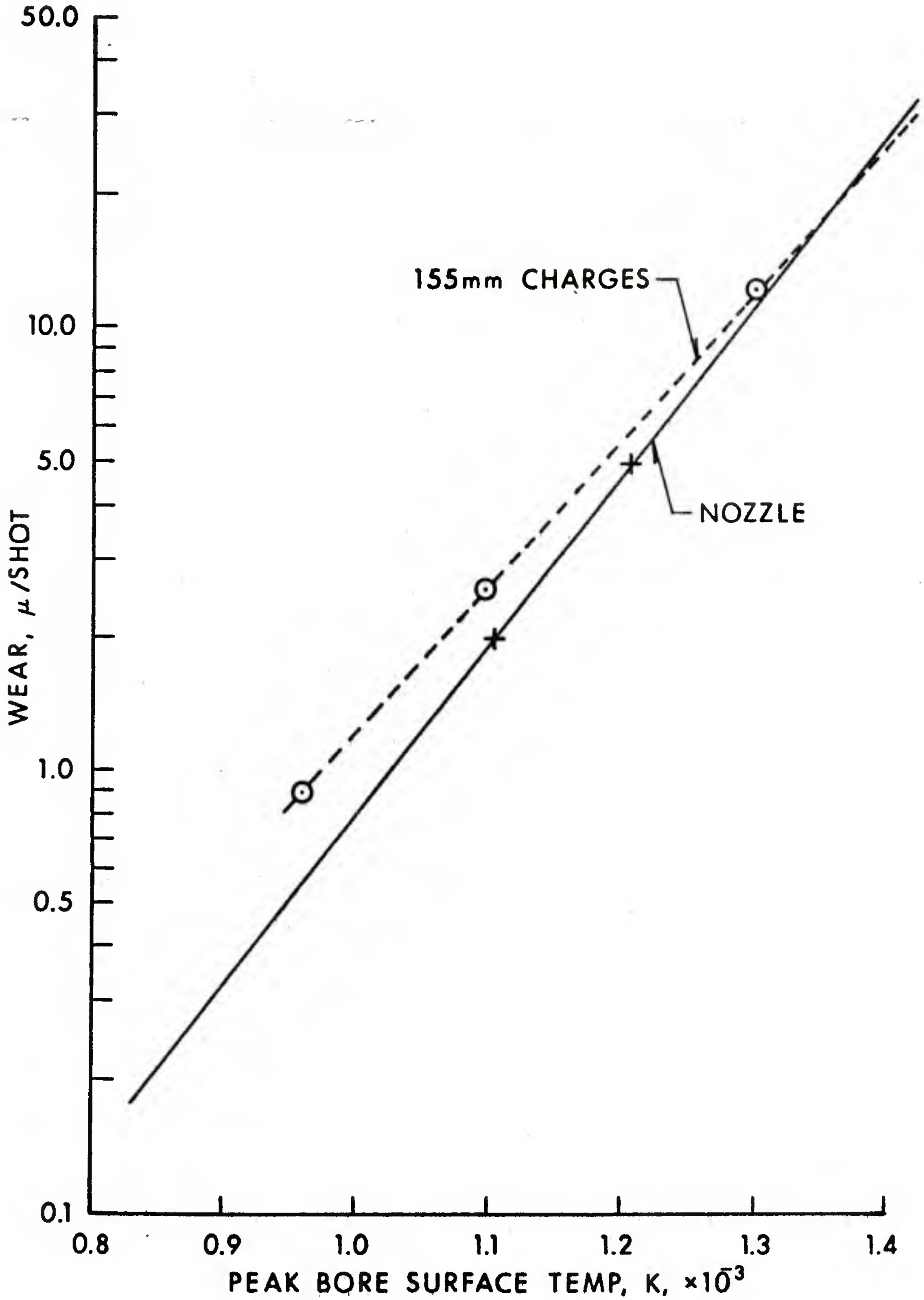

Figure 1. Wear *vs* Peak Bore Surface Temperature

Some other observations from the calculations of bore surface temperatures can be made from comparisons of bore surface temperature vs. time for the 37mm blowout gun and a 3"/70 Naval gun depicted in Figures 2-4. Table 8 summarizes pertinent heat transfer data for the three figures.

TABLE 8. CALCULATED HEAT INPUT AND SURFACE TEMPERATURES FOR 3"/70 AND 37mm BLOWOUT GUNS

Gun	Nozzle Diameter,mm	$1/\lambda$	Propellant	Charge Mass,g	Flame Temp,K	Surface Temp,K	Heat Input,J/mm^2
37mm	17.3	253	HFP	89.8	3,255	1,235	0.78
3"/70	-	280	Picrite	3991.	2,065	1,224	1.13
37mm	13.3	239	M1	159	2,417	1,254	1.21

The first point of interest is the short heating time of the blowout gun in Figure 2 vs. the 3"/70 Naval gun. As a result of the longer heating time, the 3"/70 gun reaches the same peak bore surface temperature with a much cooler propellant. The effect of the longer heating time is also reflected in the larger total heat input for the gun. The figures also point out why propellants with flame temperatures near 3800K would be needed to get the wear/shot characteristic of tank guns with the 17.3 mm nozzle. Figure 4 shows that M1 propellant produces an equivalent peak temperature as HFP if charge mass is increased and nozzle diameter is decreased. A new chamber would be required in the 37mm gun to be able to load 160g of propellant.

IV. CONCLUSIONS

1. Bore surface temperature vs. time were computed for 17.3 mm diameter nozzles in the BRL 37mm blowout gun in order to test dependence of wear vs. peak bore surface temperature.

2. The natural logarithm of wear from the nozzle was shown to be linearly dependent on peak bore surface temperature which agrees with empirical wear models and with calculations of peak bore surface temperatures by Calspan Corp. for the 155mm M185 cannon. It was shown the slope is 10% steeper in the nozzle suggesting relative propellant erosivity with the 17.3mm diameter nozzle may be exaggerated slightly compared to large caliber guns.

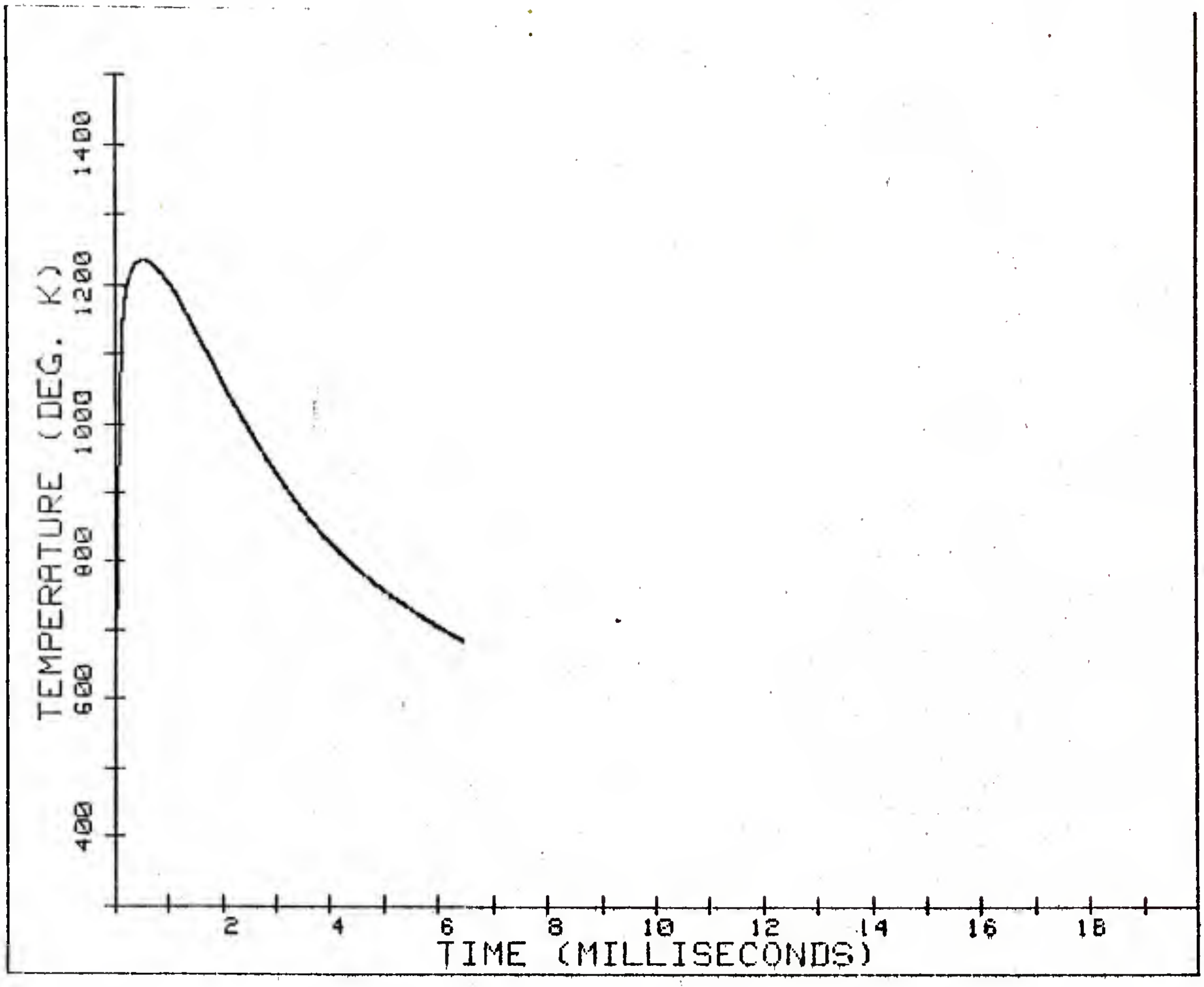

Figure 2. Temperature *vs.* Time in 37mm Blowout Gun (17.3mm Diameter Nozzle-HFP Propellant).

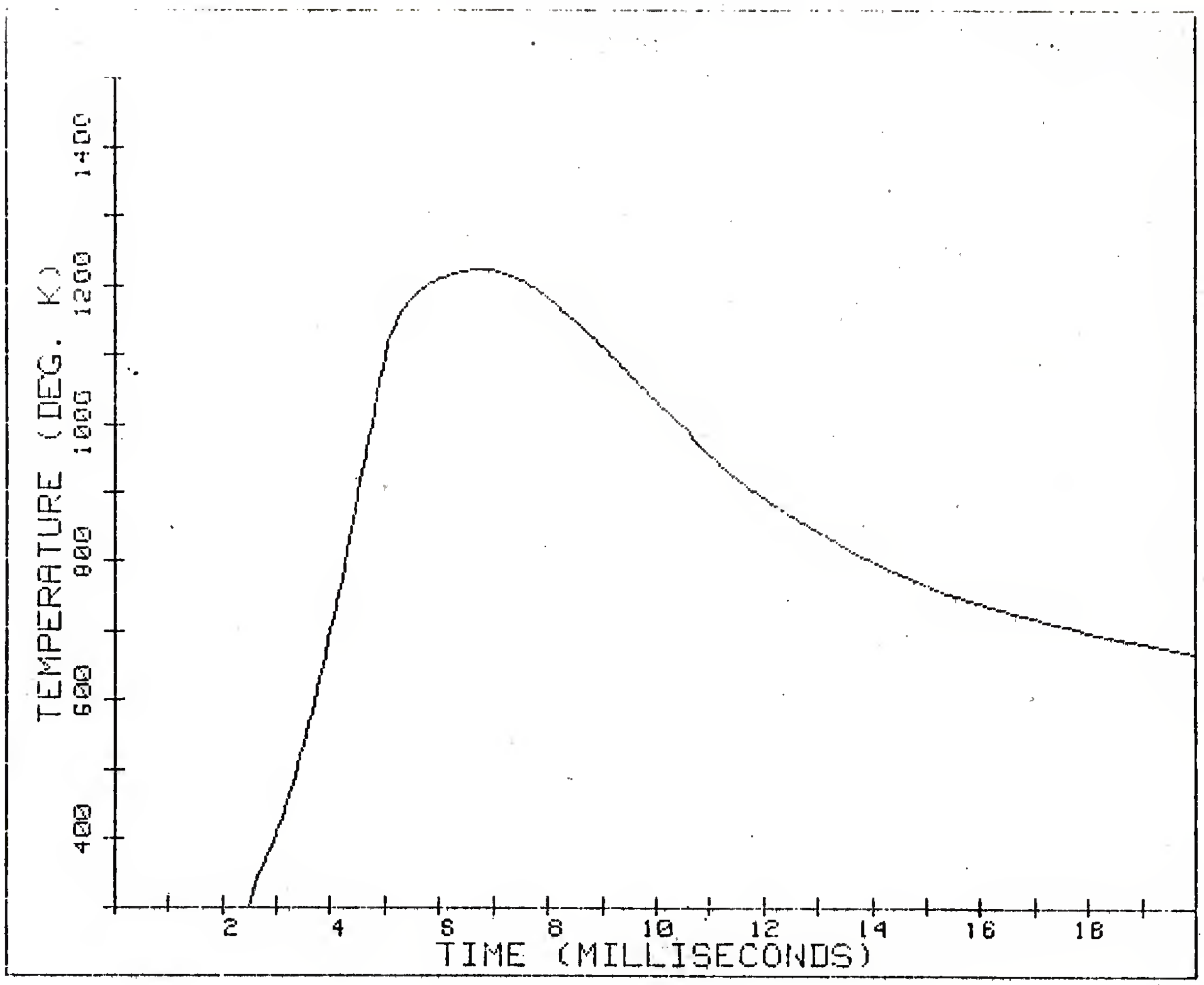

Figure 3. Temperature vs. Time in 3"/70 Gun With Picrite Propellant.

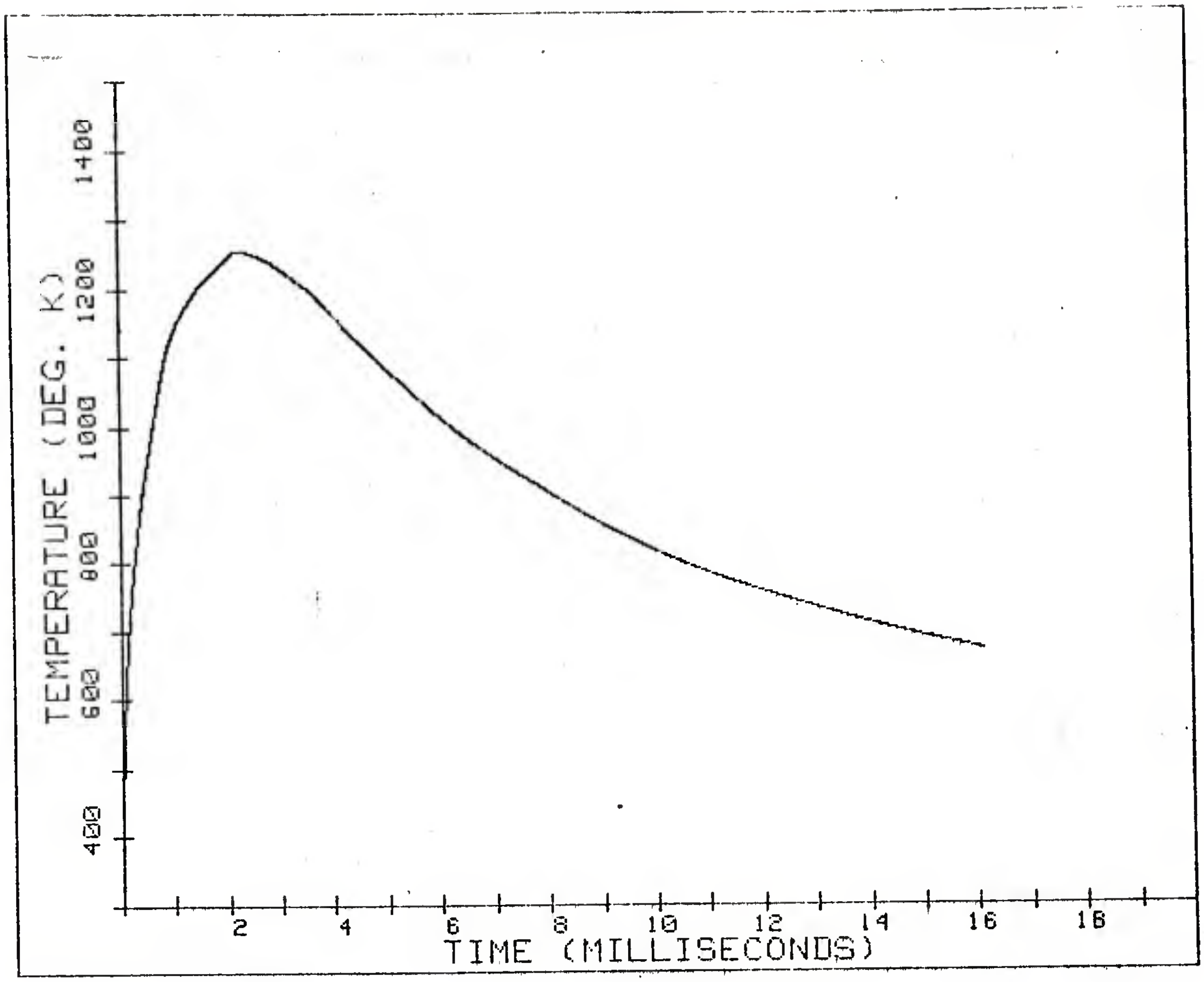

Figure 4. Temperature vs. Time in 37mm Blowout Gun (13.3mm Diameter Nozzle-M1 Propellant).

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15. J.A. Demaree, "155mm M185 Tube Wear Test of Charge, Propelling XM201," Interim Report, JPG-76-601, June 1976.

APPENDIX

COMPUTER CODES

COMPUTER CODES

The first program, "IB3/70", computes interior ballistics data for guns.

The second program, "NOZZLE", computes interior ballistics data for a blowout gun with an erosion nozzle.

The third program, "newnsn" computes heat transfer and conduction data. The program "newnsn" uses information stored on files "DATA" and "DATA1" by "IB3/70" or "NOZZLE".

Input data begins in line 2860. Data to be stored in each line is as follows:

Line	Data
2860	Projectile weight (lbs)
2870	Projectile travel (inches), chamber volume (cu.in.)
2880	Pidduck-Kent constant, integration step size (sec)
2890	Estimated projectile velocity (ft/sec), bore diameter(in), bore area (sq.in.)
2900	Shot start pressure (psi)
2910	Igniter weight (pounds)
2920	Igniter impetus (in lb_f/lb_m), ratio of specific heats, flame temperature (°K), covolume (cu.in./lb)
2930	Propellant weight (lbs)
2940	Propellant force (in lb_f/lb_m), ratio of specific heats, flame temperature (°K), covolume (cu.in./lb), density(lb/cu.in.)
2950	Propellant grain diameter (in), length (in), perforation diameter (in), and number of perfs
2960	Propellant identification (an alphanumeric string)
2970	P1, B(where the burning rate (in/sec) is B*(space mean pressure in psi + P1)), number of integration steps per printout, expected peak chamber pressure (psi), expected peak acceleration (g's).
2980	Number of "resistive pressures" listed, followed by the appropriate number of pairs of travel distance(in) and resistive pressure (lb/sq.in.)
2990-3020	These lines are used by the program to aid in calculating the fraction of the 7 perf grain burnt after splintering.
3025	Use this line to provide data if called for by the input statements

Data requested by input statements:

"Number of parameters to be varied": Enter a number (0 to 5).

"Number of proj wt, cham vol, pmax, travel distance, charge wt": The number of non-zero enteries should be as indicated in the immediately previous input. The values for the parameters indicated should have been listed in line 3025 of the program.

"Option No 2"

Enter a number (0 to 7). The program will then perform as indicated below:

NUMBER ENTERED	ACTION
0	Compute IB trajector for input data (i.e., data in lines 2860-2980)
1	Change B to match indicated peak pressure
2	Change charge weight to match indicated pressure
3	Change B to match indicated acceleration
4	Change charge weight to match indicated acceleration
5	Change charge weight to match indicated velocity
6	Print out a blurb of the above
7	Same as 0, but program writes data on files DATA DATA1 for future use.

Note that if the first input requested was not zero multiple runs will be performed. This is not useful if "Option number 2" is 7.

```
10  OPTION BASE 1
20 OVERLAP
30  DIM C(50)
40  DIM P$[10]
50  DIM T(2,10),F(2,12),R(6,3)
60  Eheat=0
70  LET Z6=0
80  DEF FNA(Y9)=INT(Y9*1000)/1000
90  READ G1,G2,G3,G5,G6,G7,G8,G4,G9
100  LET E7=G7*12
110  READ I1,I2,I3,I4,I5
120  READ P1,P2,P3,P4,P5,P6,P7,P8,P9,P0
130  READ P$
140  READ A,B,M2,M3,A9
150  IF P0<>7 THEN 190
160  LET W1=(P7-3*P9)/4
170  LET W2=((P7-W1)^2-7*(P9+W1)^2)/(P7^2-7*P9^2)
180  GOTO 200
190  LET W1=1000
200  READ K
210  FOR I=1 TO K
220  READ T(1,I),T(2,I)
230  NEXT I
240  FOR I=1 TO 12
250  READ F(1,I),F(2,I)
260  NEXT I
270  PRINT "nUMBER OF PARAMETERS TO BE VARIED"
280  INPUT D
290  IF D=0 THEN 510
300  PRINT "NO OF PROJ WT,CHAM VOL,PMAX,TRAVEL DIST,CHARGE WT"
310  INPUT D1,D2,D3,D4,D5
320  IF D1=0 THEN 360
330  FOR N1=1 TO D1
340  READ L(N1)
350  NEXT N1
360  IF D2=0 THEN 400
370  FOR N2=1 TO D2
380  READ M(N2)
390  NEXT N2
400  IF D3=0 THEN 470
410  FOR N3=1 TO D3
420  READ Q(N3)
430  NEXT N3
440  FOR N4=1 TO D4
450  READ W(N4)
460  NEXT N4
470  IF D5=0 THEN 510
480  FOR N5=Q TO D5
490  READ Y(N5)
500  NEXT N5
510  PRINT "OPTION NO 2   (0<=X>=5)   ; INPUT 6 fOR EXLANATION"
520  INPUT C1
530  IF C1<6 THEN 760
540  IF C1=6 THEN 620
550  C1=0
560  CREATE "DATA",126
570  CREATE "DATA1",3
580  ASSIGN #1 TO "DATA"
581  BUFFER #1
590  ASSIGN #2 TO "DATA1"
600  Eheat=1
610  GOTO 930
620  PRINT
630  PRINT
640  PRINT
650  PRINT "TO MATCH";TAB(20);"BY ADJUSTING";TAB(41);"INPUT"
```

```
660  PRINT
670  PRINT "NOTHING";TAB(43);"0"
680  PRINT "PMAX";TAB(20);"BETA";TAB(43);"1"
690  PRINT "PMAX";TAB(20);"CHARGE WT";TAB(43);"2"
700  PRINT "ACCEL";TAB(20);"BETA";TAB(43);"3"
710  PRINT "ACCEL";TAB(20);"CHARGE WT";TAB(43);"4"
720  PRINT "VELOCITY";TAB(20);"CHARGE`WT";TAB(43);"5"
730  PRINT
740  PRINT
750  INPUT C1
760  IF D=0 THEN 930
770  IF D1=0 THEN 800
780  FOR N1=1 TO D1
790  LET G1=L(N1)
800  IF D2=0 THEN 830
810  FOR N2=1 TO D2
820  LET G3=M(N2)
830  IF D3=0 THEN 860
840  FOR N3=1 TO D3
850  LET M3=Q(N3)
860  IF D4=0 THEN 890
870  FOR N4=1 TO D4
880  LET G2=W(N4)
890  IF D5=0 THEN 930
900  FOR N5=1 TO D5
910  LET P1=Y(N5)
920  NEXT N5
930  LET J1=I1*I2/(I3-1)
940  LET J2=J1/I4
950  LET J3=I1*I2/I4
960  LET J5=I1*I5
970  LET Q1=P1*P2/(P3-1)
980  LET Q2=Q1/P4
990  LET Q3=P1*P2/P4
1000 LET Q4=P1/P6
1010 LET Q5=P1*P5
1020 LET Q6=I1+P1
1030 Q7=P8*(P7^2-P0*P9^2)
1040 LET Q8=G6/2
1050 LET O1=.38*G8^1.5*(G2+G3/G4)*(P4-300)
1060 LET O1=O1/(1+.6*G8^2.175/P1^.8375)/(144*G7*G7)
1070 LET H1=O1+(G1+Q6/G5)/772
1080 LET O2=1/(P3-1)
1090 LET H2=1+Q6/(G1*G5)
1100 LET O3=1/((2*O2+3)/G5+2*(O2+1)*G1/Q6)
1110 LET H3=(1-O3)^(-O2-1)
1120 LET H4=G4*386/G1
1130 IF M2>=150 THEN 1160
1140 PRINT "TIME      DIST      PRES      VEL       TEMP      ";
1150 PRINT "FR.       ACCEL     BASE"
1160 LET T=1000
1170 LET T2=T(2,1)
1180 LET N=0
1190 LET M1=1
1200 LET R(1,1)=R(1,2)=R(1,3)=B0=Z=T2=S=B3=B4=B5=Z5=Z6=0
1210 LET X1=R(1,2)
1220 LET V1=R(1,3)
1230 FOR I=1 TO 3
1240 LET R(2,I)=R(1,I)
1250 NEXT I
1260 LET J=2
1270 GOSUB 2280
1280 LET S=S+Q8
1290 LET J=3
1300 FOR I=1 TO 3
1310 LET R(2,I)=R(2,I)*G6
```

```
1320 LET R(3,I)=R(1,I)+R(2,I)/2
1330 NEXT I
1340 GOSUB 2280
1350 LET J=4
1360 FOR I=1 TO 3
1370 LET R(3,I)=R(3,I)*G6
1380 LET R(4,I)=R(1,I)+R(3,I)/2
1390 NEXT I
1400 GOSUB 2280
1410 LET J=5
1420 LET S=S+Q8
1430 FOR I=1 TO 3
1440 LET R(4,I)=R(4,I)*G6
1450 LET R(5,I)=R(1,I)+R(4,I)
1460 NEXT I
1470 GOSUB 2280
1480 FOR I=1 TO 3
1490 LET R(5,I)=R(5,I)*G6
1500 LET R(1,I)=R(1,I)+(R(2,I)+R(3,I)*2+2*R(4,I)+R(5,I))/6
1510 LET R(6,I)=R(1,I)
1520 NEXT I
1530 LET J=6
1540 IF Eheat THEN PRINT #1;V,X,P1*Z/(G3+G4*X-P1*(1-Z)/P6),T
1550 IF M2*INT(M1/M2)<>M1 THEN 1590
1560 PRINT S*1000;TAB(8);FNA(R(1,2));TAB(18);INT(B0);TAB(27);
1570 PRINT INT(R(1,3)/12);TAB(34);INT(T);TAB(45);FNA(Z);
1580 PRINT TAB(54);INT(A1/386.09);TAB(63);INT(B2)
1590 IF R(1,2)>=G2-25 THEN 1610
1600 GOTO 1630
1610 N=N+1
1620 LET C(N)=B2
1630 IF R(1,2)>=G2 THEN 1730
1640 LET M1=M1+1
1650 LET V=R(1,3)
1660 IF B0<=B3 THEN 1210
1670 LET A5=A1/386.09
1680 LET B3=B0
1690 LET B8=B2
1700 LET B4=S
1710 LET B5=R(1,2)
1720 GOTO 1210
1730 LET X=(G2-X1)/(R(1,2)-X1)
1740 LET V=V1+X*(R(1,3)-V1)
1750 LET S1=S-Q8
1760 LET Z9=C(N-1)+X*(C(N)-C(N-1))
1770 IF C1=0 THEN 1960
1780 Branch=C1
1790 IF (Branch>=1) AND (Branch<6) THEN ON Branch GOTO 1800,1830,1860,1890,1920
1800 IF ABS(B3-M3)<200 THEN 1960
1810 LET B=B/(1-.85*(M3-B3)/(M3+B3))
1820 GOTO 1940
1830 IF ABS(B3-M3)<200 THEN 1960
1840 LET P1=P1/(1-.9*(M3-B3)/(M3+B3))
1850 GOTO 1940
1860 IF ABS(A9-A5)<100 THEN 1960
1870 LET B=B/(1-1.1*(A9-A5)/(A9+A5))
1880 GOTO 1940
1890 IF ABS(A9-A5)<100 THEN 1960
1900 LET P1=P1/(1-.9*(A9-A5)/(A9+A5))
1910 GOTO 1940
1920 IF ABS(G7-V/Q2)<10 THEN 1960
1930 LET P1=P1/(1-1.5*(G7-V/12)/(G7+V/12))
1940 LET E7=V
1950 GOTO 930
1960 PRINT
1970 IF Eheat=0 THEN 2000
```

```
1980 CALL Ej(#1,#2,P1/(G3+G2*G4),(V),S,G6,T,P5,G2+G3/G4,G8,G3/G4)
2000 IF M2>=500 THEN 2190
2010 PRINT "PROJ.WT. =";G1;"LBS."
2020 PRINT "INIT. CHAM. VOL. =";G3;"CU. IN."
2030 PRINT "CHG WT =";P1;"LBS."
2040 PRINT "TRAVEL DIST. =";G2;"IN."
2050 PRINT "MUZZLE VELOcITY =";INT(V/12);"F/S"
2060 PRINT "MAX. CHAM. PrES. =";INT(B3);"PSI AT";B4;"SEC. OR";B5;"IN."
2070 PRINT "MAX. BASE PRES. =";INT(B8);"PSI"
2080 PRINT "MUZZLE PRESSURE = ";INT(Z9);"PSI AT ";S1;"SEC"
2090 PRINT "MAX. ACCEL =";INT(A5);"GS"
2100 IF Z<1 THEN 2130
2110 PRINT "FRACTION BURNT =";Z;"AT";Z5;"IN FROM MUZZLE"
2120 GOTO 2140
2130 PRINT "FRACTION BURNT =";Z
2140 PRINT "BETA";B
2150 PRINT
2160 PRINT G9,I1,T(1,1),T(2,1),T(1,2),T(2,2)
2170 PRINT
2180 GOTO 2740
2190 IF E9=1 THEN 2240
2200 PRINT "PROJ WT   DIST  CHAM VOL   CW     PMAXP    "
2210 PRINT "IV     ACCEL       BETA"
2220 LET E9=1
2230 PRINT
2240 PRINT TAB(1);G1;TAB(8);G2;TAB(15);G3;TAB(24);P1;TAB(32);
2250 PRINT INT(B3);T;B(40);INT(V/12);TAB(48);INT(A5);TAB(56);B
2260 PRINT
2270 GOTO 2740
2280 LET U=R(J,1)
2290 LET X=R(J,2)
2300 LET V=R(J,3)
2310 IF Z>=1 THEN 2350
2320 IF U>=W1 THEN 2400
2330 LET Z=1-(P8-U)*((P7-U)^2-P0*(P9+U)^2)/Q7
2340 GOTO 2470
2350 LET Z=1
2360 IF Z6=1 THEN 2470
2370 LET Z5=G2-X
2380 LET Z6=1
2390 GOTO 2470
2400 FOR K=1 TO 12
2410 IF F(1,K)*W1>U THEN 2440
2420 NEXT K
2430 GOTO 2350
2440 LET W3=(U/W1-F(1,K-1))/(F(1,K)-F(1,K-1))
2450 LET W4=(P8-U)/P8
2460 LET Z=1-W4*(F(2,K-1)+(F(2,K)-F(2,K-1))*W3)*W2
2470 LET T1=0
2480 IF X=0 THEN 2560
2490 FOR K=2 TO 10
2500 IF X<=T(1,K) THEN 2530
2510 LET T1=T1+(T(1,K)-T(1,K-1))*(T(2,K)+T(2,K-1))/2
2520 NEXT K
2530 LET T2=T(2,K-1)+(T(2,K)-T(2,K-1))*(T(1,K)-X)/(T(1,K)-T(1,K-1))
2540 LET T1=T1+(T2+T(2,K-1))*(X-T(1,K-1))/2
2550 LET T1=T1*G4
2560 LET T=(J1+Q1*Z-H1*V*V-T1)/(J2+Q2*Z)
2570 LET V0=G3+G4*X-Q4*(1-Z)-J5-Q5*Z
2580 IF V0<0 THEN 2600
2590 GOTO 2620
2600 PRINT G3,G4,Q4,J5,Q5,Z
2610 GOTO 3030
2620 LET B1=T*(Q3*Z+J3)/V0
2630 LET B2=B1/H2
2640 LET B0=B2*H3
```

```
2650 IF X<>0 THEN 2670
2660 IF B1<G9 THEN 2690
2670 LET A1=H4*(B2-T2)
2680 GOTO 2700
2690 LET A1=0
2700 LET R(J,1)=2*B*(B1+A)
2710 LET R(J,2)=V
2720 LET R(J,3)=A1
2730 RETURN
2740 IF D=0 THEN 2850
2750 IF D5=0 THEN 2770
2760 NEXT N5
2770 IF D4<=0 THEN 2790
2780 NEXT N4
2790 IF D3=0 THEN 2810
2800 NEXT N3
2810 IF D2=0 THEN 2830
2820 NEXT N2
2830 IF D1=0 THEN 2850
2840 NEXT N1
2850 PAUSE
2860 DATA  15
2870 DATA 185.84,360
2880 DATA 3,.00005
2890 DATA  3400,3,7.21
2900 DATA  2500
2910 DATA  .02
2920 DATA  1.152E+06,1.25,2000,30
2930 DATA  8.8
2940 DATA  3445000,1.269,2065,32.81,.056
2950 DATA  .1425,.35,.0132,7
2960 DATA  "EX6586"
2970 DATA 6500,.000056673,200,52300,0
2980 DATA  2,0,1800,500,1800
2990 DATA  1,1,1.006,0.967,1.024,0.874,1.055,0.735
3000 DATA  1.101,0.569,1.162,0.395,1.24,0.233
3010 DATA  1.292,0.191,1.347,0.104,1.409,0.049
3020 DATA  1.48,0.014,1.557,0
3030 STOP
3990 SUB Ej(#1,#2,Rhoi,Vi,Ti,Dt,Tempi,Ada,Xm,D,C1)
4000 OPTION BASE 1
4005 OVERLAP
4020 Eoa=Eob=0
4060 Xt=Xm
4070 Kount=Ti/Dt
4120 Vi=Vi/Xm
4130 Rh=1/Rhoi
4140 Tp=0
4150 Gm1=.25
4160 Cv=.34
4170 INPUT "Cv,Ada,Gm1",Cv,Ada,Gm1
4180 A110:Kount=Kount+1
4190 Tp=Tp+Dt
4200 T=Ti+Tp
4210 Dem=1+Vi*Tp
4220 V=Vi/Dem
4230 Rho=Rhoi/Dem
4240 Temp=Tempi*((Rh-Ada)/(1/Rho-Ada))^Gm1
4250 V=V*Xm
4260 PRINT #1;V,Xt,Rho,Temp
4270 IF Kount MOD 4<>0 THEN A110
4280 IF Eoa THEN A40
4281 IF V*Rho>=100 THEN A110
4290 Eoa=1
4300 Dt=4*Dt
4301 PRINT #1;1E51,0,0,0
```

```
4305 GOTO A110
4310 A40:IF Rho>=.00050 THEN A110
4315 PRINT #1;1E51,0,0,0
4320 Xm=Xt
4330 Dt=Dt/4
4340 PRINT #2;Rhoi,Vi,Ti,Dt,Tempi,Ada,Xm,D,C1
4360 SUBEND
4370 END
```

"NOZZLE"

Input data is lines 110 and 120 corresponds to the READ statements of lines 20 and 30. Input dat is as follows:

Parameter	Data
F0	Initial web fraction remainging. (0<F0<1) If F0 is too small the initial pressure will exceed the intended nozzle start pressure.
Beta, P1	The assumed burning rate, in inches per second, is Beta (P+P1)/W where P is the chamber pressure in psi and W is the web size (inches)
C	Charge weight (pounds)
Rhop	Propellant density (lb/cu.in.)
Ada	Propellant covolume (cu.in/lb.)
T0	Adiabatic flame temperature (°K)
Gamma	Ratio of specific heats
Force	Impetus (in lb_f/lb_m)
C0,C2,C2P	These are the k_0, k_2, and $-k_2'$ of NDRC A142 of 5 Feb 1943; they are used to help calculate the amount of propellant that has been burnt.
V0	Chamber volume (cu.in.)
Ast	Area of the erosion nozzle (sq.in.)
Pstart	Nozzle start pressure (psi)
G6	Integration step size (sec)

```
10 OVERLAP
20   READ F0,Beta,P1,C,Rhop,Ada,T0,Gamma,Force,C0,C2,C2p
30   READ V0,Ast,Pstart,G6
40   Si=S=0
50   Zeta=(2/(Gamma+1))^(1/(Gamma-1))
60   Ep=(1-2*Zeta)/Gamma
70   Phelp=(2/(Gamma+1))^(Gamma/(Gamma-1))
80   Q8=G6/2
90   Break=0
100  IMAGE DD.DDDD,DD.DDD,DDDD.DDDD,DDDDDD,DDDDDDDDD,DDD.DDDDD,8D
110  DATA 0.500,.005200,6500,.300,.057,32.81,2065,1.269,3445000,.8502,.1329,.367
1
120  DATA 19.2,.090,41000,.000050
130  R(1,1)=F0
140  R(1,2)=0
150  Kount=0
160  CREATE "DATA",126
170  CREATE "DATA1",3
180  ASSIGN #1 TO "DATA"
190  ASSIGN #2 TO "DATA1"
200  BUFFER #1
210  FOR I=1 TO 2
220  LET R(2,I)=R(1,I)
230  NEXT I
240  LET J=2
250  GOSUB 660
260  LET S=S+Q8
270  LET J=3
280  FOR I=1 TO 2
290  LET R(2,I)=R(2,I)*G6
300  LET R(3,I)=R(1,I)+R(2,I)/2
310  NEXT I
320  GOSUB 660
330  LET J=4
340  FOR I=1 TO 2
350  LET R(3,I)=R(3,I)*G6
360  LET R(4,I)=R(1,I)+R(3,I)/2
370  NEXT I
380  GOSUB 660
390  LET J=5
400  LET S=S+Q8
410  FOR I=1 TO 2
420  LET R(4,I)=R(4,I)*G6
430  LET R(5,I)=R(1,I)+R(4,I)
440  NEXT I
450  GOSUB 660
460  FOR I=1 TO 2
470  LET R(5,I)=R(5,I)*G6
480  LET R(1,I)=R(1,I)+(R(2,I)+R(3,I)*2+2*R(4,I)+R(5,I))/6
490  LET R(6,I)=R(1,I)
500  NEXT I
510  PRINT USING 100;S,Z,Si,T,P,Rho,Ust
520  IF Ust=0 THEN 210
530  Kount=Kount+1
540  PRINT #1;Ust,1,Rhost,Tst
545  IF Kount MOD 4<>0 THEN 210
550  IF NOT Break OR (Rho>.0035) THEN 210
570  IF S1 THEN S1a
580  S1=1
590  PRINT #1;1E51,0,0,0
600  G6=4*G6
605  Q8=4*Q8
610  GOTO 210
615 S1a:  IF Rho>.001 THEN 210
620  PRINT #1;1E51,0,0,0
630  PRINT #2;0,0,0,G6/4,0,Ada,1,1.25*SQR(Ast),1
```

```
640  LOAD "newnsn"
650  STOP
660  F=R(J,1)
670  Si=R(J,2)
680  Z=(1-F)*(C0+C2p*F)
690  IF Z>1 THEN Z=1
700  IF F>0 THEN Z=(1-F)*(C0+C2*F)
710  IF F<-.5 THEN Z=1
720  Zhelp=V0-C*(1-Z)/Rhop
730  Vpres=Zhelp-(C*Z-Si)*Ada
740  Vth=Zhelp-C*Z*Ada
750  T=T0*(Vth*(Z-Si/C)/(Vpres*Z))^(Gamma-1)
760  P=Force*(C*Z-Si)*T/(T0*Vpres)
770  Break=Break OR (P>Pstart)
780  Rho=(C*Z-Si)/Zhelp
790  Sigma=Rho/(1-Ada*Rho)
800  R(J,1)=-Beta*(P+P1)
810  IF NOT Break THEN RETURN
820  Helper=Ep*Ada*Sigma
830  Sigmast=Zeta*Sigma*(1+Helper)
840  Rhost=Sigmast/(1+Ada*Sigmast)
850  Tst=2*T*(1+(Gamma-1)*Helper)/(Gamma+1)
860  Pst=Phelp*P*(1+Gamma*Helper)
870  Ust=SQR(386*Gamma*Pst*(1+Ada*Rhost)^2/Rhost)
880  R(J,2)=Ast*Ust*Rhost
890  RETURN
```

"newnsn"

The data listed in this program should not normally be changed. Input parameters are requested as indicated below. Default values are as indicated.

Message	Keyboard Entry
0 FOR GRAPHS, 1 FOR NO GRAPHS	0 or 1
TIMM, TEMPM	Maximum time (sec) and temperature (°K) to be shown on graph
ENTER LABEL	An alphanumeric label for the graph
GUN TEMPERATURE?	Temperature of gun steel (default is 300°K)
ALCP	$\lambda * C_p$ (default is $0.4/(14.8 + 4*\log_{10} D)^2$, where D is the gun caliber in centimeters)
XINT, TINT	Distance from idealized breech (inches) for these calculations, time to stop calculations or go to next round (sec) (default = projectile base or nozzle throat, D/100)
NRDS, NLA, IPROPT, LHELP	Number of rounds in this burst, number of mathematical layers, print option (0 for full print, 1 for 1/4 as much, 2 for very little printing), mathematical layer to use for bore surface between rounds (default: 1, 7, 0, 4)
INSIDE DIAMETER, OUTSIDE DIAMETER	Inside and outside diameter of the gun (inches)

```
1  OPTION BASE 1
5   DIM Label$[40]
6    INPUT "0 FOR GRAPHS,1 FOR NO GRAPHS",Eng
7    IF Eng THEN 355
10   PLOTTER IS "GRAPHICS"
11   PEN 2
12   DEG
20   INPUT "TIMM,TEMPM",Timm,Tempm
25   LINPUT "ENTER LABEL",Label$
26   Label=LEN(Label$)
30   LOCATE
40   SCALE -Timm/10,Timm,200,Tempm+100
45   CLIP -Timm/100,Timm,290,Tempm
50   AXES .001,100,0,300
55   UNCLIP
60   CSIZE 3
70   LDIR 0
80   LORG 5
90   FOR I=.002 TO Timm-.001 STEP .002
100  MOVE I,270
110  LABEL USING "DD";I*1000
120  NEXT I
121  LDIR 90
130  LORG 5
140  FOR I=400 TO Tempm STEP 200
145  MOVE -.030*Timm,I
150  LABEL USING "DDDD";I
170  NEXT I
180  LORG 5
190  MOVE -.06*Timm,(300+Tempm)/2
200  CSIZE 4
201  LDIR 90
210  LABEL USING "20A";"TEMPERATURE (DEG. K)"
220  LDIR 0
230  MOVE Timm/2,230
240  LABEL USING "19A";"TIME (MILLISECONDS)"
250  MOVE Timm/2,Tempm+50
260  CSIZE 6,.5
270  LDIR 0
290  LORG 5
295 PEN 1
300  LABEL USING "30A";Label$
310  PEN 3
320  FRAME
330  PEN 4
340  MOVE 0,300
355 OVERLAP
361  DIM Ac(99),Al(99)
370  DIM Isthe(7),Th(99,4,7),Dr(99,7),Ista(7),Isto(7),Jp(7),Dt(7),Ds(7),Alph(40)
,Ak(40),Hold(7),Kno(7)
371  DIM Ah(4)
372  MAT READ Ah
373  DATA .25,1,.5,.333333333333
374  Ipropt=1
380  READ Tht,Eopr,Lhelp,Tmax,Nordf
381  MAT Hold=(Tht)
390  DATA 300,1,4,0,1
400  ASSIGN #8 TO "DATA"
405  BUFFER #8
410  ASSIGN #7 TO "DATA1"
411  Eof=0
420  READ #7;Rhoi,Vi,Ti,Du,Tempi,Ada,Xm,D,Xint
421  Xi=Xint
430  INPUT "GUN TEMPERATURE?",Tht
440  MAT Th=(Tht)
510  MAT READ Ista,Isto,Jp,Isthe
```

```
520  DATA 1,5,7,8,9,9,9,7,11,13,15,15,15,15,4,4,4,4,4,4,4,1,5,7,8,9,9,9
530  READ Eread,Er,Er0,Enew,Eos
540  DATA 1,1,1,0,1
550  Erh=0
560 H2=1E50
570  Erh=0
580  READ S,Irds,Nrds,Kosh
590  DATA 0,1,1,0
600  Alcp=.4/(14.8+4*LGT(D))^2
610  INPUT "ALCP?",Alcp
620  INPUT "XINT,TINT?",Xint,Tint
630  INPUT "NRDS,NLA,IPROPT,LHELP?",Nrds,Nla,Ipropt,Lhelp
640  T=Q=Tcal=0
730  Lim=Lmin=1
740  Tint=D*100
750  Nla=7
760  MAT READ Ak,Alph
770  DATA 0,0,0,0,0,.108,.108,.107,.106,.105,.103,.101,.098,.096,.095,.088,.083,
.078,.073,.068,.062,.058,.06,.068,.089,.107,.122,.130,.135,.140,.145,.145
780  DATA 0,0,0,0,0,0,0,0
790  DATA 0,0,0,0,0,.128,.122,.115,.109,.103,.096,.09,.084,.078,.072,.066,.061,.
055,.049,.046,.045,.048,.056,.07,.089,.113,.128,.135,.140,.145,.150,.150
800  DATA 0,0,0,0,0,0,0,0
820  Alphm=0
830  FOR K1=1 TO 40
840  Alphm=MAX(Alphm,Alph(K1))
850  NEXT K1
860  Tdesir=Tint
870  Alce=422.5*Alcp
880  Hspace=SQR(Du*Alphm*3)
890  Const=Du/(Hspace*Hspace)
900  FOR K1=1 TO 40
910  Alph(K1)=Const*Alph(K1)
920  Ak(K1)=Const*Ak(K1)
930  NEXT K1
940  Alcp=Alce*Hspace*Const
950  PRINT "THE SPACE INTERVAL IS",Hspace
960  INPUT "INPUT INSIDE DIAM, OUTSIDE DIAM",Ri,Ro
970  Ri=2.54*Ri
980  Ro=2.54*Ro
990  Kou=8-Nla
1000 Sh=Du/Hspace
1010 Dt(Kou)=Du*1000
1020 Ds(Kou)=Hspace
1030 FOR Ko1=Kou TO 6
1040 Dt(Ko1+1)=4*Dt(Ko1)
1050 Ds(Ko1+1)=2*Ds(Ko1)
1060 NEXT Ko1
1070 Isto(7)=INT((Ro-Ri)/Ds(7)+.5)
1080 REM --CIRCULAR CORRECTIONS
1090 FOR I=Kou TO 7
1100 Istop=Isto(I)
1110 FOR Ii=1 TO Istop
1120 R=Ri+Ds(I)*Ii
1130 Dr(Ii,I)=Ds(I)/(2*R)
1131 NEXT Ii
1132 NEXT I
1140 Eoe=1
1145 Alce=Alce/12
1150 FOR K7=1 TO 4
1160 L=7
1170 Kno(7)=J=K7
1180 GOSUB Heater
1190 IF Eoe THEN J7
1200 FOR K6=1 TO 4
1210 L=6
```

```
1220 Kno(6)=J=K6
1230 GOSUB Heater
1240 IF Eoe THEN J6
1250 FOR K5=1 TO 4
1260 L=5
1270 Kno(5)=J=K5
1280 GOSUB Heater
1290 IF Eoe THEN J5
1300 FOR K4=1 TO 4
1310 L=4
1320 Kno(4)=J=K4
1330 GOSUB Heater
1340 IF Eoe THEN J4
1350 FOR K3=1 TO 4
1360 L=3
1370 Kno(3)=J=K3
1380 GOSUB Heater
1390 IF Eoe THEN J3
1400 FOR K2=1 TO 4
1410 L=2
1420 Kno(2)=J=K2
1430 GOSUB Heater
1440 IF Eoe THEN J2
1450 FOR K1=1 TO 4
1460 L=1
1470 Kno(1)=J=K1
1480 GOSUB Heater
1490 NEXT K1
1500 J2: NEXT K2
1510 J3:NEXT K3
1520 J4:NEXT K4
1530 J5:NEXT K5
1540 J6:NEXT K6
1550 J7:NEXT K7
1560 GOTO 1150
1570 Heater:IF Kosh<>0 THEN 2690
1590 DEF FNDel(Ia)=Dr(Ia,L)-(Ak(Is1)-Ak(Is3))/(4*Ak(Is2))
1600 DEF FNF(A,B,C)=Al(K)*(A*(1-De)-B-B+C*(1+De))+B
1610 DEF FNG(A,B,C,E)=E*FNF(A,B,C)+(1-E)*B
1615 Eopr=(Ipropt=1) OR (Ipropt=2) AND (J=1)
1620 Jp(L)=J
1630 Rv=0
1640 Istart=Ista(L)
1650 Istop=Isto(L)
1660 I1=Istart+1
1670 I2=Istop-1
1680 Jhe=1+(J+2) MOD 4
1690 IF J=1 THEN Hold(L)=Th(Istop,4,L)
1700 FOR I=Istart TO Istop
1710 L1=Th(I,Jhe,L)/50
1720 P1=L1 MOD 1
1725 L1=INT(L1)
1730 Al(I)=Alph(L1)-P1*(Alph(L1)-Alph(L1+1))
1740 Ac(I)=Ak(L1)-P1*(Ak(L1)-Ak(L1+1))
1750 NEXT I
1760 IF L=7 THEN Outside
1770 REM --OUTER STEP OF LAYER
1780 Is=Ista(L+1)
1790 L1=Th(Is,Jp(L+1),L+1)/50
1800 K=Istop
1810 De=Dr(K,L)-(Ac(Istop-2)-Ak(L1)-P1*(Ak(L1)-Ak(L1+1)))/(4*Ac(Istop))
1820 Th(Istop,J,L)=FNG(Th(Istop-2,4,L),Th(Istop,4,L),Th(Is,Jp(L+1),L+1),Ah(J))
1830 Outside:FOR K=I1 TO I2
1840 De=Dr(K,L)-(Ac(K-1)-Ac(K+1))/(4*Ac(K))
1850 Th(K,J,L)=FNF(Th(K-1,Jhe,L),Th(K,Jhe,L),Th(K+1,Jhe,L))
1860 NEXT K
```

```
1870 IF L=7 THEN Th(Istop,J,7)=(2*Th(Istop-1,J,7)-Th(Istop-2,J,7)/2+1.8)/1.506
1880 REM --THIS ASSUMES K=.11,H=.00067,AND AMBIENT TEMP IS 300 K
1890 IF L=Lmin THEN A40
1900 Is=Isto(L-1)
1910 L1=Th(Is-1,1,L-1)/50
1920 P1=L1 MOD 1
1930 De=Dr(Istart,L)-(Ak(L1)-P1*(Ak(L1)-Ak(L1+1))-Ac(Istart+1))/(4*Ac(Istart))
1940 K=Istart
1950 Th(Istart,J,L)=FNF(Hold(L-1),Th(Istart,Jhe,L),Th(Istart+1,Jhe,L))
1960 IF Eopr THEN PRINT USING 1965;S,Rv,Q,L,Th(Istart,J,L),Th(Istart+1,J,L),Th(I
start+2,J,L),Th(Istart+3,J,L)
1965  IMAGE  DDDZ.D,8DZ,6DZ.DD,4D,7DZ.D,7DZ.D,7DZ.D,7DZ.D
1970 GOTO Helper
1980 A40:S=S+Dt(L)
1990 IF Eread THEN A50
2000 IF Eos AND (Th(1,J,L)<1.5*Th(5,J,L)) THEN A120
2010 A45:Th(1,J,L)=(2*Th(2,J,L)-Th(3,J,L)/2)/1.5
2020 Enew=(S>=Tdesir)
2030 IF Eopr THEN PRINT USING 1965;S,Rv,Sq,L,Th(Istart,J,L),Th(Istart+1,J,L),Th(
Istart+2,J,L),Th(Istart+3,J,L)
2040 GOTO Helper
2045 A50:  M=M+1
2046 READ #8;V,X,Rho,Tgas
2047 X=X+Xi
2050 IF V>1E49 THEN A70
2060 A60:Vgas=0
2070 IF X>Xint THEN Vgas=V*Xint/X
2080 H1=Alce*Rho*Vgas
2090 Z=H1*H2/(H1+H2)
2100 Coef=Z*Sh/Ac(1)
2110 Th(1,J,L)=(2*Th(2,J,L)-Th(3,J,L)/2+Coef*Tgas)/(1.5+Coef)
2111 Rv=Z*(Tgas-Th(1,J,L))
2112 IF Eng THEN 2120
2113 IF S>Timm*1000 THEN Eng=1
2119 DRAW S/1000,Th(Istart,J,L)
2120 Q=Q+(Rv+Rhov)*Dt(L)/2000
2130 IF Eopr THEN PRINT USING 1965;S,Rv,Q,L,Th(Istart,J,L),Th(Istart+1,J,L),Th(I
start+2,J,L),Th(Istart+3,J,L)
2140 Rhov=Rv
2150 GOTO Helper
2160 A70:IF Er THEN A80
2170 Eread=0
2180 GOTO A60
2190 A80:Er=0
2200 REM -----STEP SIZE INCREASE
2210 Sh=2*Sh
2220 A100:S=S-Dt(L)
2230 Lmin=Lim=Mm=L+1
2240 Ii=Ista(Mm)-1
2250 Jj=Kno(Mm)
2260 FOR I=1 TO Ii
2270 Th(I,Jj,Mm)=Th(2*I-1,4,Mm-1)
2275 NEXT I
2280 Ista(Mm)=1
2290 Kosh=3
2300 Kount=0
2310 GOTO 2360
2320 A120:IF J<>1 THEN A45
2330 Kount=Kount+1
2340 Eos=(L<Lhelp)
2350 ON Kount GOTO A45,A45,A100
2360 Helper:Eoe=(Lmin>=L)
2370 Istart=Ista(L)
2380 Istop=Isto(L)
2390 Tmax=MAX(Tmax,Th(1,J,1))
```

```
2400 IF Enew=0 THEN RETURN
2410 PRINT "Round no";Irds;"TIME=";S/1000;"Seconds";LIN(1);"Max temp";INT(Tmax);
"Bore surface temperature";Th(1,J,Lhelp);"Total heat input";.1*INT(10*Q)
2420 Q=0
2430 Enew=0
2440 IF Nrds<=Irds THEN CALL Wait(Nrds,Tdesir,Tint,Return)
2450 IF Return THEN RETURN
2460 Tmax=0
2470 Eos=0
2480 Irds=Irds+1
2490 Eread=Er=Ero=True
2500 Tdesir=Tdesir+Tint
2510 Sh=Sh/2
2520 Lh=L-1
2530 FOR I=1 TO Lh
2540 Jp(I)=4
2550 NEXT I
2560 I=J
2570 Mmm=L
2575 E30:Lh=M-1
2580 Ista(Mmm)=Isthe(Mmm)
2590 Is=Ista(Mmm)
2600 FOR Ka=1 TO Is
2610 Th(2*K-1,4,Lh)=Th(2*K,1,Lh)=(Th(K,I,M)+Th(K+1,I,M))/2
2620 Istop=Isto(Lh)
2630 Hold(Lh)=Th(Istop,4,Lh)
2640 Mmm=Lh
2650 I=4
2660 IF Lh>=2 THEN E30
2670 Lmin=Lim=1
2680 RETURN
2690 Kosh=Kosh-1
2700 Eoe=1
2710 RETURN
2720 SUB Wait(Nrds,Tdesir,Tint,Return)
2730 READ Nadd,Tadd
2740 DATA 0,0
2750 IF Nadd=0 THEN B10
2760 Nrds=Nadd+Nrds
2770 Tint=Tadd
2780 Return=0
2790 SUBEXIT
2800 B10:IF Tadd=0 THEN STOP
2810 Tdesir=Tdesir+Tadd
2820 Return=1
2830 SUBEND
2840 END
```

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